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# AIRCRAFT NUCLEAR PROPULSION DEPARTMENT

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PRELIMINARY STUDY FOR A NUCLEAR ROCKET ACTUATOR


S. H. Proffitt
CONTROL DESIGN SUB-SECTION


January 13, 1961

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SUBJECT: PRELIMINARY STUDY FOR A NUCLEAR ROCKET ACTUATOR

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The environmental conditions for the actuators of the nuclear rocket reactor will be significantly different from the jet engine applications with which we are most familiar. Other factors which bear on actuator selection are the source of energy available, the type of control elements used to control reactivity, and the response times which are required by the power plant system selected.

At this stage of our study all of these items of information are indefinite. From studying Los Alamos Scientific Laboratory reports and from a specification prepared by GE-AATD and LASL, I have hypothesized a first approximation to environment and attempted to predict the avenue which would be most promising. The conclusion at this time is that pneumatic actuation, using a rotary vane actuator, will be the proper choice. This is based on the assumptions of available stored gas supply in the vehicle for pneumatics and limited response available from electrical actuation.

<u>Environmental Conditions</u>

Temperature: $-250^{\circ}F$ to $+500^{\circ}F$ maximum range
$-65^{\circ}F$ to $+275^{\circ}F$ AATD specification

Radiation, total dose: $10^9$ rad maximum (AATD specification)
$3 \times 10^7$ rad (LASL Quarterly)

Heat generated in actuator material: 1 KW/lb.

Prior to operation the thermal environment may be expected to be $-65^{\circ}F$ to $150^{\circ}F$ and nuclear radiation environment, nil.

The current hypothesis is that the reactor will be brought up to 1 KW on the ground before launch and that temperature in the reactor will approach $500^{\circ}F$. It is apparent that electrical power will have to be supplied by an APU continuously if the reactor is to be held at criticality. It remains to be established whether

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or not the discharge gases from the APU could be used to cool the reactor actuators or whether the heat sink of the reactor and surrounding parts would be sufficient to keep the actuator below 500°F before hydrogen flow is initiated. This event may not take place for at least 70 seconds and, depending upon the sequence of starting the reactor and chemical first stage, the delay might be longer. It should be noted that a pneumatic actuator will be somewhat self-cooled during this time period. The integrated nuclear radiation dose will be insignificant.

The next environment imposed on the actuators will be during the 108-second power increase to 1% and thence to full power. During the latter part of this time hydrogen will be supplied to the reactor and the actuators will be shielded from reactor heat by a blanket of cold gas estimated to be -250°F to -200°F. From the AATD specification a maximum allowable hydrogen flow of 0.058 lb/sec per actuator or a total of 0.696 lb/sec for all actuators, if connected in series, may be used for cooling the actuator. It is during the 300-second (assumed) period of thrust operation that the 1 KW/lb heat will be generated in the actuator materials and the integrated dose of $3 \times 10^7$ rad will be imposed. It is noted that the AATD specification, agreed to by LASL, quotes a dose of $10^9$ rad so it would be well to assume the higher figure until we have estimates of our own.

The target mission hypothesized incorporates a 50-hour period at self-cooling temperatures between thrust operations. This implies that, if the system is designed to hold the reactor at 500°F, we may expect the ultimate actuator requirements to be this high. The integrated nuclear radiation dose will be little influenced by this power-holding period.

<u>Type of Control Elements</u>

There seems to be little reason to consider any but the drum-type of control. The Los Alamos Quarterlies identify twelve 4" diameter beryllium reflector control drums 52 inches long. The polar moment of inertia of this drum is 0.01875 slug $ft^2$ which is significantly lower than the requirement in the AATD specification of .03 slug $ft^2$ for the load. If a scram speed of 200°/sec must be reached in .02 second, the maximum acceleration is 174 radians/$sec^2$ and, therefore, the maximum torque is 62.6 in-lb for the higher inertia. (It is noted that the AATD specification only calls for 10.4 to 14.6 in-lb from the scram spring.) These figures do not suggest excessive inertia. It is currently assumed that the cooling provided by the hydrogen will prevent distortion of the long, thin drums.

The other configurations rejected primarily because of complexity were:

1. Shell drum control where only the outer shell would be driven, thus reducing inertia.

2. Translation of chains carrying poison capsules, either axial or radial motion.

3. Translation of blades driven radially.

4. Translation of rods driven axially.

Source of Energy Available

It is in considering the target mission of a 50-hour moon flight that the assumption of sufficient stored gas supply for pneumatic actuation becomes most questionable. If the reactor is to be kept critical and used for thrust at the beginning and end of the mission the stored gas supply might have to be on the order of 4500 cu. ft. just to provide quiescent flow. This assumes 300 SCFM for twelve actuators whereas the AATD specification allows 300 SCFM for a single actuator. Quiescent flow for AATD's hot gas servo is only 2 SCFM. It is to be noted that, for electrical or hydraulic actuators, an APU would be required hence energy would have to be stored in the vehicle for the full flight time. At this time, this information indicates that serious consideration be given to modifying the holding power concept.

If hydraulic actuation were provided it will be necessary to charge the weight of the pump, motor, and reservoir against the actuation system in addition to whatever size increase is necessitated in the electrical APU.

COMPARISON OF HYDRAULIC, PNEUMATIC, AND ELECTRICAL ACTUATION

Hydraulic Actuation

This mechanization would be the most readily available but would be the most susceptible to both temperature and radiation environments. It would be a severe heat transfer problem to insure that the self-heating of the oil system was properly utilized to prevent oil temperature from dropping below -20°F or rising above 250°F. This is deemed the most feasible operating range for hydraulic systems. For the target mission such a heat balance throughout the target mission would be even more unlikely.

The radiation environment, if only $3 \times 10^7$ rads, would be severe but not impossible. XDC 57-7-3 shows that Esstic 45 oil was irradiated to $10^8$ rads at 500°F with a resulting 26% viscosity change at 210°F, a three-to-one change in neutralization number, and a 2.6 ml gas evolution per ml of fluid. Such action on the oil would impose special considerations but not impossible. At 135°F the effect of $10^8$ rads nuclear dose was significantly less.

APEX 357 shows that most of the seal materials are good for only 2 - 5 hours at $2 \times 10^6$ rep/hr, therefore, these components become limiting items.

For the above reasons and in comparison with the other actuation systems hydraulic actuation is not recommended.

Electrical Actuation

Electrical actuation has been hypothesized using the D140 actuator configuration driven by an AC servo-motor. From the radiation standpoint, it is noted from APEX 357 that Alkinex insulation has little radiation stability (essentially 0 hr) at a flux of $10^7$ rep/hr. On the other hand, asbestos fiberglass insulation has about a 500-hour stability. It is implied, however, by Figure 8 that the stability might be quite low at $10^9$ rep/hr and, thus, it is assumed that even this would be inadequate for a dose of $10^9$ rad in 300 seconds. Carl Collins advises that Alkinex-insulated motors were run at Convair for 700 hours at 425°F, $10^8$ R without difficulty.

If we conclude that radiation damage might not be too severe it seems reasonable to estimate a representative motor time constant. The drum inertia of 0.03 slug $ft^2$ referred to the motor shaft through a 1570:1 gear reduction is $1.9 \times 10^{-5}$ slug $ft^2$. Choosing a 5.4 watt Kearfott R112 servo-motor as an example, the rotor inertia is $0.0295 \times 10^{-5}$ slug $ft^2$. The time constant of this motor, assumed unloaded, is 0.0207 sec. Therefore, on the basis of total-to-rotor-inertia ratio the time constant of the actuator would be 1.33 sec. The added damping of the gear train would tend to reduce this. This figure is supplied to judge the applicability of an electrical actuator when system requirements are better known. For comparison, it is noted that the AATD-LASL specification calls out a time constant of 0.055 sec for the regulating drum but does not specify it for the shims.

Although the electrical actuator is attractive from the standpoint of case pressure sealing (no rotating seal required), it is unattractive because of the high reduction gear box (backlash). Because the actuator will be cooled by hydrogen, graphite bearings should be quite feasible. Care to prevent troublesome distortion during sudden cooling will have to be exercised.

The most significant advantage of the electrical actuator appears to be the elimination of a specialized energy source. The additional power requirements are estimated to be 200 watts compared to a basic system requirement of 1500 watts or 13.3%. The additional weight would be quite small. The conclusion is, however, to derate this advantage in view of the probable need to give up power holding during coast because of the energy source size.

Electrical actuation is, therefore, rated second best to the pneumatic system on the current assumption of inadequate time constant, marginal motor insulation, and excessive backlash.

Pneumatic Actuation

For this study, the pneumatic actuator being developed by AATD for LASL was chosen as representative.

There may be development problems, particularly with the scram mechanization and damper. At this time, however, there seems to be no reason to anticipate these problems cannot be solved.

Like all the actuators, the position sensors, switches, wiring, and connectors will have to be radiation tolerant and APEX 357 suggests material selection for $10^9$ rads will be quite limited. John Blake advises that we have tested several solenoid valves under Oak Ridge irradiation for hundreds of hours without damage. It is assumed, therefore, that the AATD torque motor can be designed for adequate radiation tolerance.

The rotary vane motor loaded against the scram spring is probably the reason for allowing 1500% more quiescent airflow than is specified for the AATD hot gas servo. This appears to be the only basic limitation to development for the target mission and is directly associated with the assumption of maintaining criticality throughout the flight. The small orifice in the supply probably prevents the use of anything but chemically clean gas.

The pneumatic servo design permits conversion of the actuator from a high response (0.055 sec) to a velocity-limited configuration by simply adding an accumulator. This provides the flexibility of choosing a system with regulating drums probably not possible with the electrical actuator.

There is evidence of careful design for cooling and the flow control restriction provides the high pressure gas seal. On the whole, the design appears to be well executed and light in weight.

The size of a 3000 psi gas bottle to supply the twelve actuators for 300 seconds with quiescent flow alone is estimated to be 84 cu. ft. This assumes the full 300 SCFM allowed in the GE-LASL specification is used. It is evident, therefore, that the assumption of available gas supply has a significant influence in choosing pneumatic actuation over electrical.

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